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An Improved Scheduling Technique for Time-Triggered Embedded Systems

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Outline

- Motivation
- System Architecture
- Problem Formulation
- Scheduling Strategy
- Experimental Results
- Conclusions

Motivation

- **Embedded System Design.**
- **Scheduling, Communication, Bus Access.**

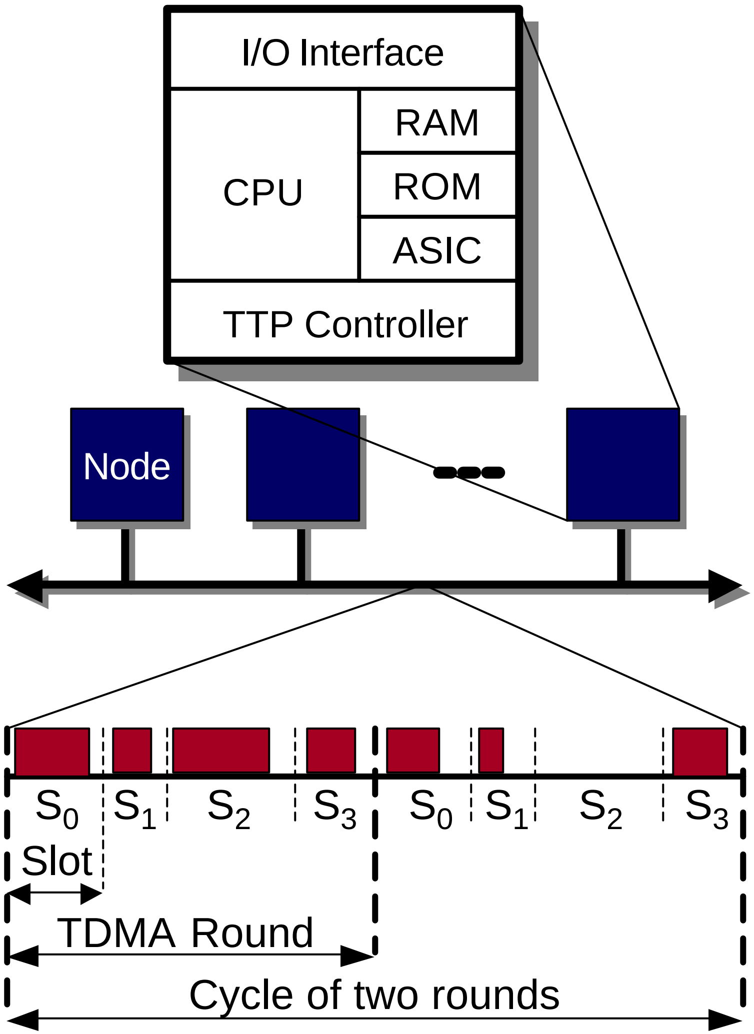
Characteristics:

- **Static nonpreemptive scheduling.**
- **System model captures both the flow of data and that of control.**
  Eles et al. Scheduling of Conditional Process Graphs for the Synthesis of Embedded Systems. DATE’98
- **Heterogeneous system architecture.**
- **Communications using the time-triggered protocol (TPP).**
  Kopetz, H., Grünsteidl, G. TTP-A Protocol for Fault-Tolerant Real-Time Systems. IEEE Computer ‘94

Message:

- **Improved schedule quality by considering the characteristics of the communication protocol.**

Hardware Architecture



- **Safety-critical distributed embedded systems.**
- **Nodes interconnected by a broadcast communication channel.**
- **Nodes consisting of: TTP controller, CPU, RAM, ROM, I/O interface, (maybe) ASIC.**
- **Communication between nodes is based on the time-triggered protocol.**

- **Bus access scheme: time-division multiple-access (TDMA).**
- **Schedule table located in each TTP controller: message descriptor list (MEDL).**

Software Architecture

- Real-Time Kernel running on the CPU in each node.
- There is a local schedule table in each kernel that contains all the information needed to take decisions on activation of processes and transmission of messages.
- Time-Triggered System: no interrupts except the timer interrupt.
- The worst case administrative overheads (WCAO) of the system calls are known:

U_t	WCAO of the timer interrupt routine
d_{PA}	process activation overhead
d_S	overhead for sending a message on the same node
d_{KS}	overhead for sending a message between nodes
d_{KR}	overhead for receiving a message from another node

Problem Formulation

Input

- **Safety-critical application with several operating modes.**
- **Each operating mode is modelled by a conditional process graph.**
- **The system architecture and mapping of processes to nodes are given.**
- **The worst case delay of a process is known:**

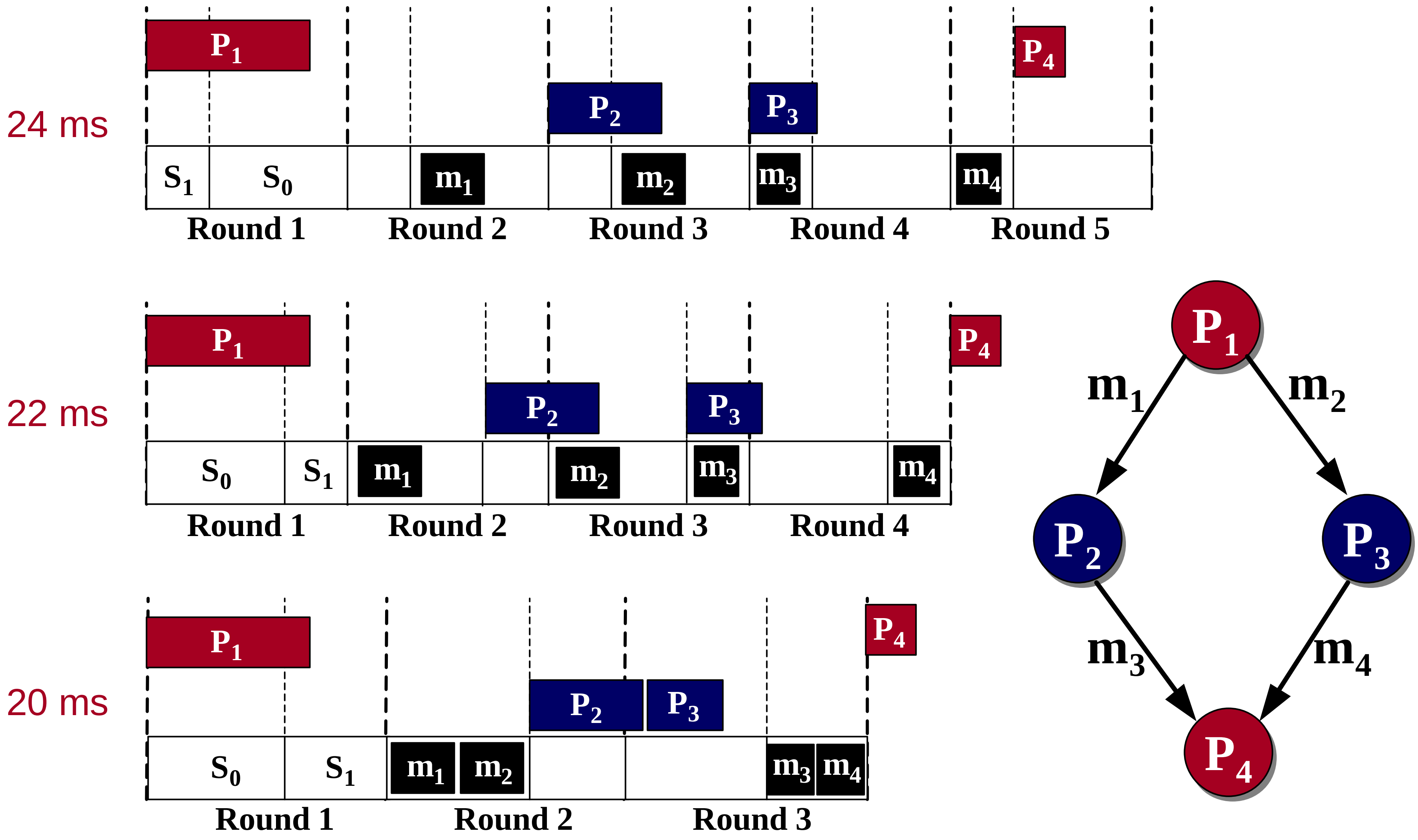
$$T_{P_i} = (d_{PA} + t_{P_i} + q_{C_1} + q_{C_2})$$

$$q_{C_1} = \sum_{i=1}^{N_{out}^{local}(P_i)} d_{S_i} \qquad q_{C_2} = \sum_{i=1}^{N_{out}^{remote}(P_i)} d_{KS_i} + \sum_{i=1}^{N_{in}^{remote}(P_i)} d_{KR_i}$$

Output

- **Local schedule tables for each node and the MEDL for the TTP controllers.**
- **Delay on the system execution time for each operating mode, so that this delay is as small as possible.**

Scheduling Example



Scheduling Strategy

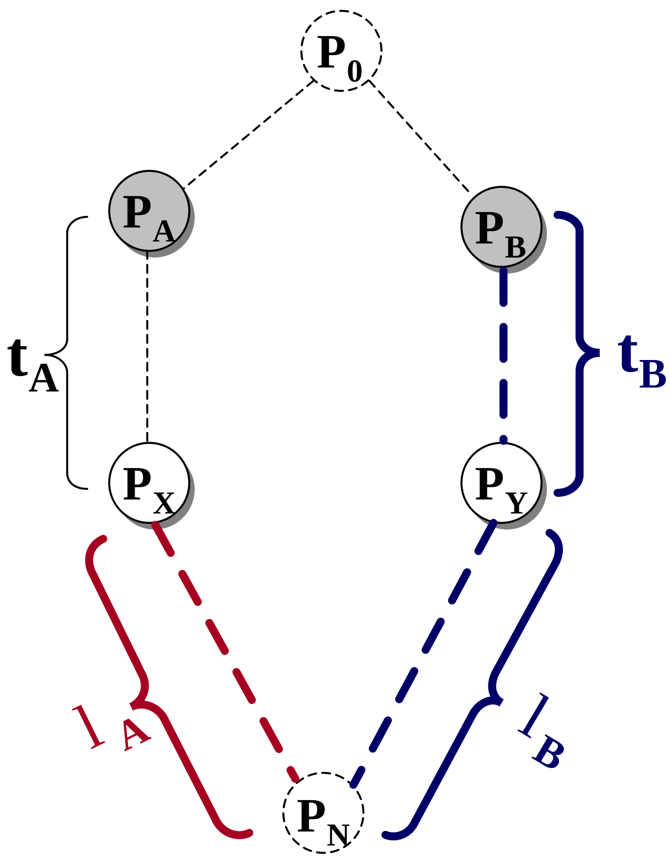
1. The scheduling algorithm has to take into consideration the TTP.

   - priority function for the list scheduling

2. The optimisation of the TTP parameters is driven by the scheduling.

   - sequence and lengths of the slots in a TDMA round are determined to reduce the delay
   - two approaches: Greedy heuristic, Simulated Annealing (SA).
   - two variants: Greedy 1 tries all possible slot lengths, Greedy 2 uses feedback from the scheduling algorithm.
   - SA parameters are set to guarantee near-optimal solutions in a reasonable time.

Partial Critical Path Scheduling



$$L_{PA} = \max(T\_curr + t_A + l_A,\ T\_curr + t_A + t_B + l_B)$$

$$L_{PB} = \max(T\_curr + t_B + l_B,\ T\_curr + t_B + t_A + l_A)$$

Select the alternative with the smaller delay:

$$L = \max(L_{PA}, L_{PB})$$

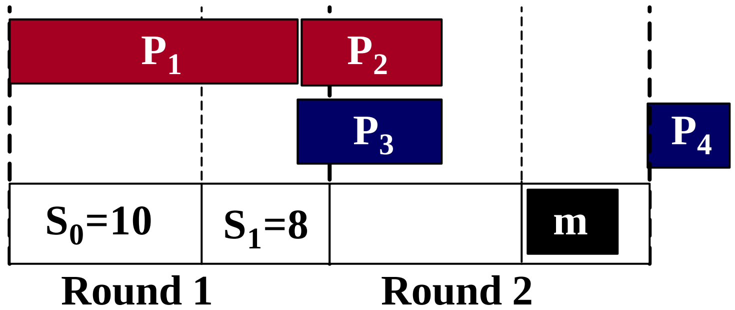
$l_A > l_B$ Þ $L_{PA} < L_{PB}$

$l_B > l_A$ Þ $L_{PB} < L_{PA}$

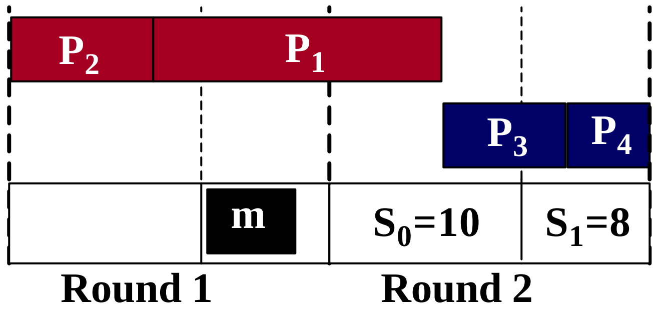
Use l as a priority criterion.

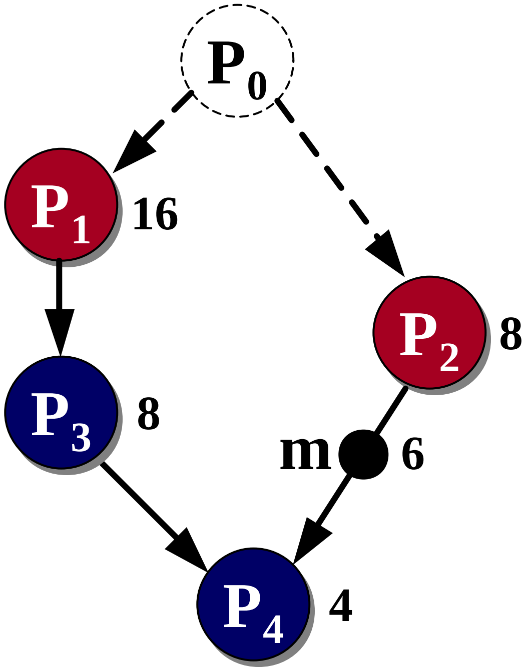
Priority Function Example

40 ms

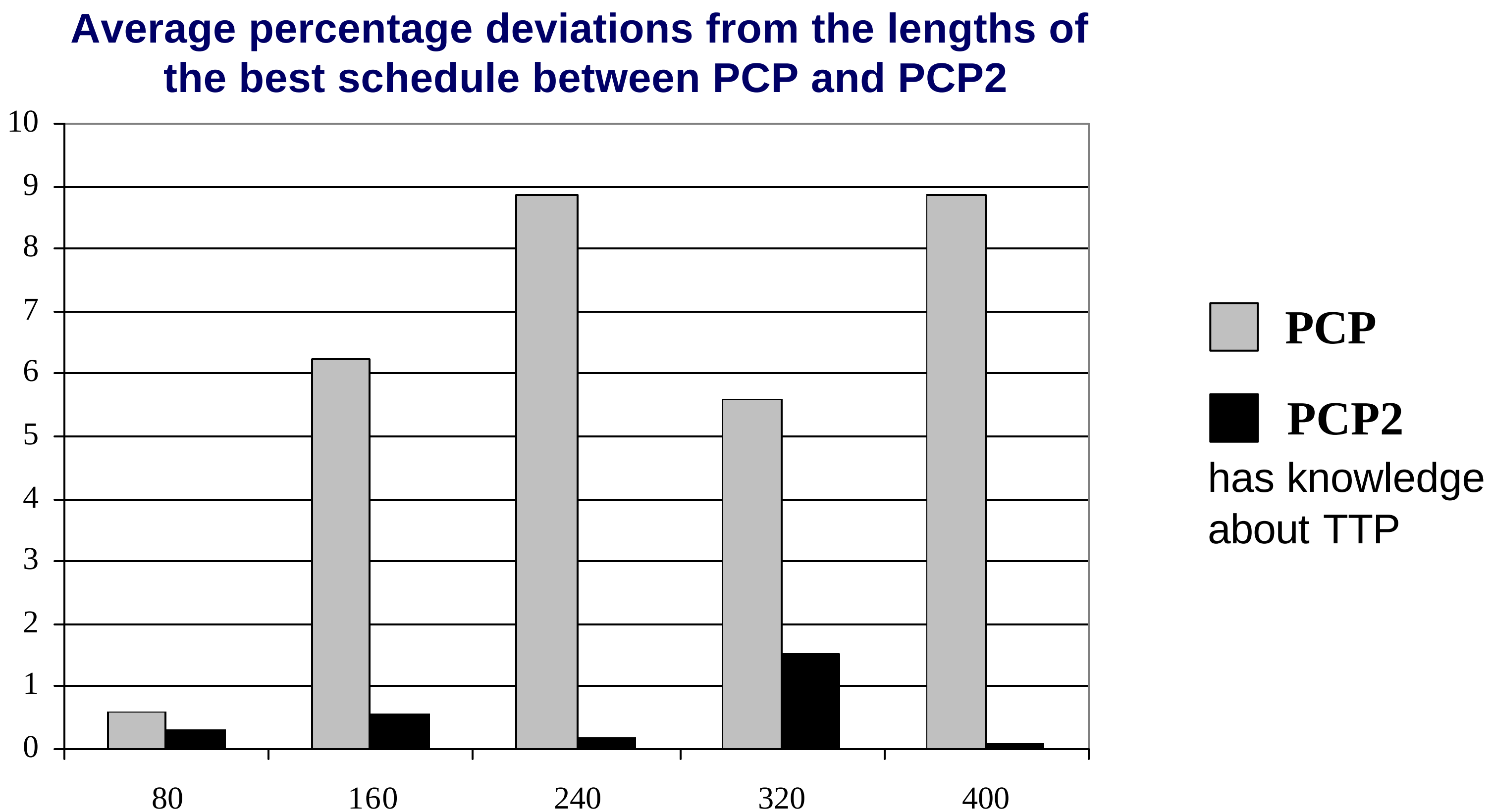


36 ms



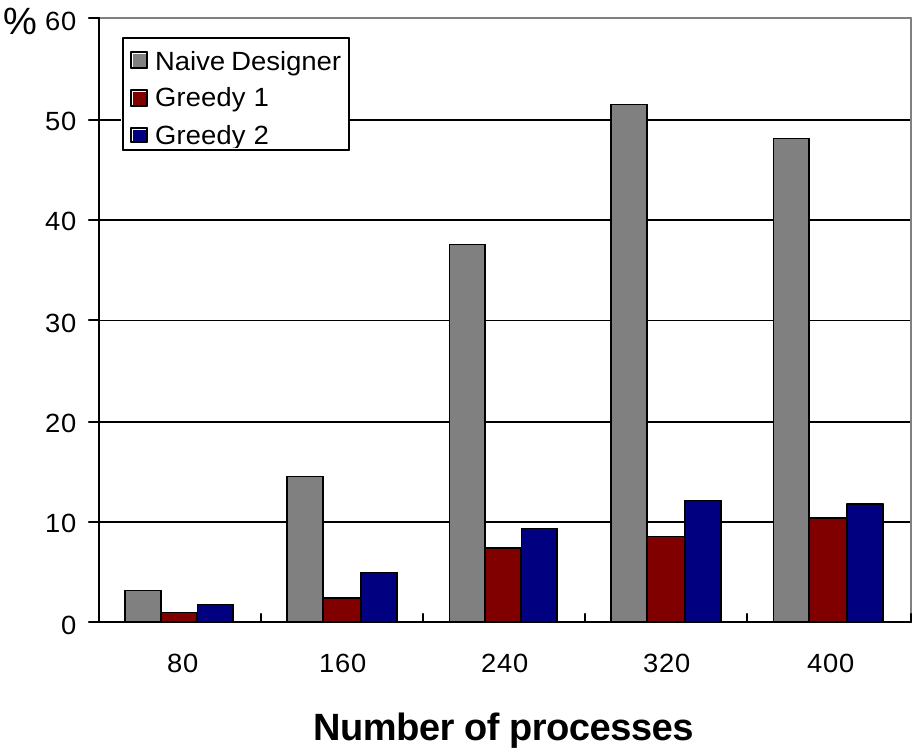


Experimental Results



Experimental Results (Cont'd)

Average percentage deviations from the lengths of near-optimal schedules



- **The Greedy approach is producing accurate results in a very short time (few seconds for graphs with 400 processes).**
- **Greedy 1 produces better results than Greedy 2 (but it is slightly slower).**
- **SA finds near-optimal results in a reasonable time.**
- **A real-life example implementing a vehicle cruise controller validated our approach.**

Conclusions

- An approach to process scheduling for the synthesis of safety-critical distributed embedded systems.
- Communication of data and conditions based on TTP.
- Scheduling algorithm tailored to the communication protocol.
- Communication has been optimised through packaging of messages into slots with a properly selected order and lengths.
- Improved schedule quality by considering the overheads of the real-time kernel and of the communication protocol.
- Evaluation based on experiments using a large number of graphs generated for experimental purpose as well as real-life examples.